

Context

Climate change from below

Paleo reconstructions have produced a number of surprises about the glacial ocean, but none were as unexpected as the surprise in Adkins et al. (2002), which showed that the bottom waters around Antarctica were significantly saltier than the rest of the ocean. The apparent cause is the accumulation of brine from the production of sea ice around the perimeter of Antarctica.

We learned from this discovery that the glacial deep ocean was much more stably stratified than it is today. Now, just as we are getting used to the idea (Adkins et al. (2005) in this issue of *Quaternary Science Reviews*), the stable glacial ocean should have been destabilized from time to time because geothermal heat would have slowly warmed the salty layer by from below. These episodes should have been climatically significant because the heat and salt in the salty bottom layer would have been abruptly released into the upper ocean. Adkins, Ingersoll, and Pasquero liken the abrupt release to the discharge of a capacitor.

Given a 0.4-psu salinity difference between a salty layer 2000 m thick and a cold fresher layer above, the salty water below will become thermobarically unstable if it can be warmed by about 2 °C. With a 50-mW/m² input of geothermal heat, it would take roughly 10,000 years to warm the layer by this amount. This time scale and the predicted 2 °C temperature change provide an intriguing match with the sequence of events associated with Heinrich Events in the North Atlantic, Bond cycles in the Greenland ice cores, and the bi-polar seesaw between Greenland and Antarctica.

Water at the location of core MD95-2042 (at 3500 m depth off the coast of Portugal) is observed to warm by up to 2 °C before Heinrich events H4, H5, and H6 between 38 and 60 thousand years ago (Shackleton et al., 2000). The air over Antarctica also warms at the same time and the $\delta^{13}\text{C}$ of the water at the core site decreases. The water at MD95-2042 then begins to cool and becomes heavier in $\delta^{13}\text{C}$ as Greenland abruptly warms. These warming and cooling cycles are separated by about 7000 years. At 3500 m, MD95-2042 is well within the salty southern layer.

The warming at MD95-2042 occurs at a time when the salty layer is presumably very stable and is isolated from the water above. The decline in $\delta^{13}\text{C}$ is due to the accumulation of CO₂ from the respiration of organic particles. According to Adkins, Ingersoll, and Pasquero, the cooling and the increase in $\delta^{13}\text{C}$ that coincide with the warming in Greenland are due to mixing with the colder, high- $\delta^{13}\text{C}$ water above in response to a discharge of the capacitor somewhere in the North Atlantic.

The proposed discharge injects salt into the upper layers of the North Atlantic, which is then available to kick start the Atlantic's thermohaline circulation in a big way. A re-invigorated thermohaline circulation then warms up Greenland and the North Atlantic region. According to Adkins, Ingersoll, and Pasquero, the warmest intervals in Greenland during Stage 3, i.e. the interstadials that follow Heinrich Events 4–6 and the Antarctic intervals A1–A4, have their origin in the deep ocean.

This is a major departure from the prevailing view (e.g. Ganopolski and Rahmstorf, 2001; Knutti et al., 2004), which attributes the climate anomalies during Dansgaard/Oeschger events and Bond cycles to changes in the freshwater input to the North Atlantic. Ganopolski and Rahmstorf attribute A1–A4 and the long cold intervals at the end of the Bond cycles to the exceptionally large freshwater input during Heinrich events. Warm interstadials follow when the freshwater forcing is no longer suppressing the thermohaline circulation. The problem with this idea is that it does not explain why the interstadials following Heinrich events are so much longer and warmer than the others. It is a discharge of the capacitor, perhaps, rather than a switch-off of the freshwater input, that brings on the unusually warm interstadials.

Adkins, Ingersoll, and Pasquero discuss a number of weaknesses in their idea, but they do not discuss the one that seems most obvious. The longest and warmest intervals in Greenland follow Heinrich Events, which take place when the North Atlantic is very cold. The thermobaric capacitor cannot cause Heinrich Events or bring about the cold conditions that precede them. Is it simply a coincidence that the thermobaric capacitor discharges after Heinrich Events? Or do the Heinrich

Events set the stage for a thermobaric discharge by making the mid-depth water in the North Atlantic exceptionally cold in relation to the warmed salty water below?

The picture remains a bit murky. As is usual with problems like these, a clear resolution of cause and effect requires very well-dated records that can establish chronological priorities in different parts of the climate system. Nevertheless, Adkins, Ingersoll, and Pasquero have given us an intriguing new perspective on abrupt climate change that builds on the groundbreaking work of Adkins et al. (2002).

References

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